Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

#- 7

O. E. S. Doc. 8.

UNITED STATES DEPARTMENT OF AGRICULTURE.
OFFICE OF EXPERIMENT STATIONS.
CIRCULAR NO. 7.

CO-OPERATIVE FIELD EXPERIMENTS
WITH
FERTILIZERS.

MARCH, 1889.

CONTENTS.

Page.

I. Letter of transmittal 5

II. Report of conference of representatives of experiment stations, regarding co-operative field experiments with fertilizers 7

III. Explanations and directions for experiments 15

IV. Suggestions for further experiments 24

  Special nitrogen experiments 24

  Results of similar experiments 28

  Special phosphoric acid and potash experiments 34

V. Sources of error 36

VI. Kinds of experimental inquiry needed 38

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., March 12, 1889.

SIR: In response to an invitation from this office under sanction of the Secretary of Agriculture, the directors of a number of experiment stations especially interested in field experiments with fertilizers met at this Department on March 5 and 6 for conference regarding plans for co-operative work. Uniform plans for soil tests with fertilizers, to be conducted by farmers under the direction of the experiment stations, were agreed upon, and suggestions were made for other experiments.

I have the honor to transmit herewith (1) report of the conference by the secretary; (2) explanations and directions for soil tests, prepared in this office after consultation with a committee appointed at the conference; and (3) suggestions for further experiments, which have also been prepared at the request of the conference. The explanations and directions for soil tests and the suggestions for other experiments are intended to be used by farmers who make experiments on their own land under direction of the stations.

The act of Congress making appropriation for the experiment stations for the coming fiscal year provides "that as far as practicable all such stations shall devote a portion of their work to the examination and classification of the soils of their respective States and Territories, with a view to securing more extended knowledge and better development of their agricultural capabilities." This work, if properly developed by the stations, may without doubt become, in the older States especially, a not unimportant part of the soil studies thus called for.

Very respectfully,

W. O. ATWATER,
Director.

HON. J. M. RUSK,
Secretary of Agriculture.

REPORT OF CONFERENCE OF REPRESENTATIVES OF EXPERIMENT STATIONS REGARDING CO-OPERATIVE FIELD EXPERIMENTS WITH FERTILIZERS.

By Chas. E. Thorne, Secretary.

In response to a call issued by Prof. W. O. Atwater, Director of the Office of Experiment Stations of the United States Department of Agriculture, under authority of the Secretary of Agriculture, a number of directors of experiment stations, and others interested in field and plot experimentation met in conference in the library of the Department of Agriculture, on Tuesday and Wednesday, March 5 and 6, 1889, for the purpose of adopting, if practicable, a uniform method of conducting such experiments.

The conference assembled at 11 a. m., March 5. Professor Atwater was called to the chair, and Director Charles E. Thorne, of Ohio, was appointed secretary. At the request of Professor Atwater, Professor Jones, of Florida, and President McBryde, of South Carolina, presided during the larger portion of the meeting. The following gentlemen were in attendance, either at the opening or during subsequent sessions of the conference:

Henry E. Alvord, director Maryland Experiment Station, Agricultural College, Md.; H. P. Armsby, director Pennsylvania Experiment Station, State College, Pa.; W. O. Atwater, director Office of Experiment Stations, United States Department of Agriculture, and director Storrs School Experiment Station, Storrs, Conn.; W. H. Bishop, horticulturist Maryland Experiment Station, Agricultural College, Md.; W. P. Brooks, agriculturist Hatch Experiment Station, Amherst, Mass.; A. W. Harris, assistant director Office of Experiment Stations, United States Department of Agriculture; A. I. Hayward, agriculturist Maryland Experiment Station, Agricultural College, Md.; W. L. Jones, director Georgia Experiment Station, Athens, Ga.; A. C. Magruder, West Virginia Experiment Station, Morgantown, W. Va.; J. M. McBryde, director South Carolina Experiment Station, Columbia, S. C.; A. T. Neale, director Delaware College Experiment Station, Newark, Del.; H. J. Patterson, chemist Maryland Experiment Station, Agricultural College, Md.; E. D. Porter, director Minnesota Experiment Station, Saint Anthony Park, Minn.; H. E. Stockbridge, director Indiana Experiment Station, La Fayette, Ind.; C. E. Thorne, director Ohio Experiment Station, Columbus, Ohio; G. H. Whitcher, director New

Hampshire Experiment Station, Hanover, N. H. Twelve stations, in as many States, were thus represented. Delegates from several others had expected to attend but were unfortunately prevented.

At the request of the meeting Professor Atwater suggested an outline for the work of the conference, proposing that it deal first with the plans and methods for field experiments with fertilizers, especially such as may be conducted in co-operation with farmers. He believed that such experiments might be useful for bringing the stations into connection with the farmers, for their educational value to the farmers who make them and to the communities which the experimenters influence, and for the information that might be obtained from them. Such work had been in progress in several States for a number of years. Both Connecticut stations had done a good deal during the past season. Professor Phelps, vice-director of the Storrs School Experiment Station, had personally visited farmers in various sections of the State, starting the experiments, inspecting the crops during growth, and assisting at harvest. An unfavorable season and early frosts had interfered with much of the work, yet some of the experiments had given results of value. In previous and more favorable seasons better results had been obtained. The farmers of the State had become much interested in the experiments, and both Connecticut stations were planning to continue the work.

Professor Atwater also called attention to the provision of the act of Congress making appropriations for the stations for the next fiscal year, which calls upon the stations, as far as practicable, to devote a portion of their work to studies of soils, with a view to securing more extended knowledge and better development of their agricultural capabilities, and thought this would be a useful preliminary measure.

Dr. A. T. Neale, now director of the Delaware College Experiment Station, but for a number of years connected with the New Jersey State Station, which has done much work of this character, stated emphatically that he would not give it up. The chief difficulty he had found had been the inequality of soils. This difficulty might be partially overcome by duplication of plots, which he urged. Dr. Neale stated that he proposed to carry out in Delaware such experiments as had been performed in New Jersey, but with more unfertilized plots in each experiment.

In reply to an inquiry as to the cost to the stations Professor Atwater said that the Storrs Station in Connecticut, after selecting two or more farmers in each county, including some who had been previously engaged in such work and who manifested a willingness to continue it, had supplied them with materials, including fertilizers and a spring balance for weighing, and paid a certain compensation for the work. This compensation was intended to cover use of land, time expended in labor, etc. Two series of experiments had been made, the one involving the use of eleven plots, of one-tenth acre each, the other requiring twenty plots or more, of one-tenth or one-twentieth acre each.

The compensation had varied with different circumstances from $15 to $50 or thereabouts. But the circumstances the past season had been somewhat peculiar, and the amounts paid could not be taken as a measure of what would be paid in the future. According to his experience much of the best experimenting was done by the men who demanded the least remuneration.

Dr. Neale estimated the average cost to the station for conducting these tests, *i. e.* the amount paid to the farmer for use of land, labor, etc., but not including materials and travel, at $15 per acre.

President Alvord suggested a series of topics for consideration in connection with the subject under discussion, and on motion a committee, composed of Messrs. Armsby, Thorne, and McBryde, was instructed to formulate these suggestions and report the same as a basis for future discussion. The conference then adjourned until 2 p. m.

On re-assembling, the committee reported the following recommendations:

(1) That for the present, soil-tests with fertilizers, made upon some such plan as recommended in Bulletin No. 1 of the Storrs School Agricultural Experiment Station, be made a leading feature of this work.

(2) That such plan, when adopted, provide for the use of uniform quantities of fertilizing elements, based upon chemical analysis of the fertilizers used. (Subsequently amended so as to recommend "the use of uniform kinds and quantities of fertilizing materials." See beyond.)

(3) That experiments be continued throughout a series of years, when practicable, and that the fertilizers be repeated on the same plots year after year while the particular crops used be left to the discretion of the stations. (Dr. McBryde objected to the continuous application of fertilizers on the same plots, as recommended by the majority of the committee, preferring to use new land each season for this work.)

(4) That both manured and unmanured plots be duplicated to as great an extent as may be found practicable.

(5) That in distribution of such experiments regard be had to the surface geology of the State.

(6) That reports upon such experiments should contain as full information as can be furnished respecting the geological origin and history of the soil on which they may be made, its physical and chemical condition, and its fauna and flora, and also as full meteorological data as can be obtained.

It was not deemed advisable to recommend any special methods for the location of these tests among competing farmers.

With the exceptions noted this report was adopted as the general sense of the conference, which then entered into discussion of the details of the plan proposed.

SHAPE AND SIZE OF PLOTS.

Dr. Neale had found plots 14 feet wide and of sufficient length to contain one-tenth acre each better adapted than other sizes to the use of machinery in harvesting. For the same reason plots 16 feet wide had been adopted in Ohio.

The danger of plants on fertilized or unfertilized plots extending their roots to contiguous fertilized plots, and getting the benefit of materials not intended for them, was discussed. On motion of Professor Porter it was recommended that the plots be separated by alley-ways not less than 3 feet wide, and that the latter be kept clean by cultivation.

On motion of President Alvord it was voted that the conference recognize the necessity of leaving the form of the plots to be governed by local conditions.

After some discussion respecting the size of the plots, one-twentieth of an acre was recommended, there being two dissenting votes.

METHODS OF APPLYING FERTILIZERS.

In respect to methods of application, it was the general sense of the conference that the larger portion, at least, should be applied broadcast, both for the reason that there is danger of injury to the seed and young plant if strong manures come in contact with it, and that the crop should have the fertilizer within reach of its roots throughout its growth. It was advised that nitrate of soda be sown in the spring, rather than in the fall, and Dr. McBryde suggested that in the case of corn and cotton the ration of nitrate should be divided into two or three top-dressings, to be applied at intervals during the growing season.

During the afternoon, Hon. Norman J. Colman, the retiring Secretary of Agriculture, favored the conference with his presence and a brief address.

The conference adjourned until 10 a. m., Wednesday. On re-assembling, the question of recommending a definite arrangement of experiments was considered.

On motion of Dr. Armsby, it was voted not to formulate any recommendation relative to time and manner of applying fertilizers.

KINDS AND QUANTITIES OF FERTILIZERS.

The plan of using fertilizers containing nitrogen, phosphoric acid, and potash, singly, two by two, and all three together was adopted.

In discussing the quantities of fertilizers to be used, attention was called to the fact that these experiments are intended rather as preliminary surveys than as accurate scientific tests, and therefore that, for practical purposes, the use of fertilizers of standard composition would accomplish the objects in view quite as well as the more exact apportionment of fertilizing elements by analysis, as proposed in the second section of the recommendations of the committee. On motion of President Alvord this section was amended so as to read as follows:

(2) That we recommend the use of uniform kinds and quantities of standard fertilizing materials.

Referring to the quantities recommended in the plan proposed in the Storrs Station Bulletin, Dr. McBryde stated that the quantity of potash there given would be deemed excessive in South Carolina, while that of nitrogen might be slightly increased. Professor Whitcher, however, opposed any reduction in the quantity of potash. The argument in both cases was the same, viz, that a wide divergence from the established practice of the section in which the experiments were made would to some extent discredit the work, and that, where such practice had been founded upon experience, such divergence might mislead some by inducing an unprofitable use of fertilizers. It was deemed essential, however, for purposes of comparison, that all should agree to use uniform quantities upon certain plots, although it might be thought best to use also larger or smaller quantities upon other plots, for local reasons. In connection with this subject, the question was discussed whether the quantities used should be multiples of 16, or the quantities used in the Connecticut, New Jersey, and other experiments. Professor Atwater said multiples of 16 would have been adopted by the Storrs station last spring but for the fact that other numbers were in use elsewhere. On account of the manifest convenience of multiples of 16, which allow a whole number of pounds for each square rod, and because this rate of application had been adopted in two or more of the States represented in the conference, it was decided to recommend that this rate be uniformly adopted. The use of gypsum plots was recommended in order that the sulphate of lime of the gypsum might offset that in the superphosphate, and also because of the general fertilizing action of gypsum. By formal vote the following quantities were recommended for general adoption:

For nitrogen, nitrate of soda, 160 pounds per acre, containing 16 per cent nitrogen.

For phosphoric acid, dissolved bone-black, 320 pounds per acre, containing 16 per cent soluble phosphoric acid.

For potash, muriate of potash, 160 pounds per acre, containing 50 per cent potash.

For sulphate of lime, 160 pounds high grade gypsum per acre.

MARKING PLOTS.

The question of marking plots being under consideration, Dr. Neale stated that he had used sections of inch gas pipe, driven below the surface, so as to be out of reach of tillage implements, and located by triangulation and measurement from permanent stone monuments at the side of the field. President Alvord had used pipes, driven in the headlands at the ends of the plots, with temporary stakes in the plots. Professor Porter had used standard monuments at the corners of the sections of plots, with oak stakes marking the plot corners and temporary stakes carrying the plot labels. With respect to the materials for these labels, it was stated that an iron stake, with a socket in which to slip a zinc label, could be bought. It was urged that the letters of the labels be large and distinct, so as to be easily read by visitors in carriages. It was voted to recommend that the outside corners of sections or series of plots be marked with sections of gas pipe, driven to or below the surface, and that at least one such stake be driven along each side of the section.

CORRECTIONS FOR MISSING HILLS.

Dr. McBryde stated that cotton re-plant is often a failure, though it may sometimes produce a better crop than the original planting. The long continuance of the harvesting season is one cause of this uncertainty. Professors Whitcher and Porter stated that in their latitude it was seldom possible for replanted corn to make a fair growth; but the statement was made that in the corn belt proper—Ohio and westward—it would often be impossible to distinguish the re-plant from the original planting. It was finally voted to recommend that when practicable missing hills be replanted (in order to equalize conditions of light, soil-space, etc.), but that in computing results the re-plants be rejected from the computation.

WHERE AND HOW TO OBTAIN FERTILIZERS.

The conference was unanimously of the opinion that if the stations could unite in a general contract with a single firm of manufacturers they would get not only better terms but, especially, a more uniform grade of fertilizers. In respect to the purchase of fertilizers weighed out and packed in small bags ready for immediate application to the plot, Dr. Neale stated that the foremen of the fertilizer establishments disliked these small bags in the midst of the busy season, and he was very doubtful whether the desired accuracy in the weighings and mixtures could be insured. It was suggested that much might be saved by having suitable bags made under one contract for the entire list of stations. Upon motion of President Alvord, it was voted to appoint a committee on materials and supplies to negotiate for fertilizers, bags, and such other supplies needed by the stations as might advantageously be purchased in this manner. Messrs. Alvord, Neale, and Armsby were named for this service.

PLANTING IN HILLS OR DRILLS.

Dr. McBryde had seen very little difference in the two methods with respect to cotton, and the Ohio station experiments were referred to as showing that there seemed to be but little difference in respect to corn. The matter was left without any recommendation.

DUPLICATION OF PLOTS.

Great stress was laid upon the importance of duplicating plots. Dr. McBryde asked for an expression of opinion as to whether fertilized plots should be compared with contiguous unfertilized plots or with the average of the unfertilized plots of the series. It was the general opinion that the contiguous or nearest unfertilized plots should be used as the basis of comparison, giving due weight to their respective distances from the fertilized plot, but that the entire report or at least the range of yield should go on record. Professor Atwater gave some account of European discussion of this topic and urged the advantage of duplicating the fertilized plots where feasible.

ARRANGEMENT OF PLOTS WITH REFERENCE TO THE POINTS OF THE COMPASS.

It was recommended that the plots should extend north and south, when the contour of the land would permit.

NAMES FOR CO-OPERATIVE TESTS.

It was voted to use the name of *Farm Tests* to designate such work as is done by farmers under the direction of the stations, as it was the opinion of those present that the use of the term station—as substation, branch station, etc.—should be restricted to places where the work is directly superintended by a regularly appointed officer of the control station. It was thought best to designate the particular experiments here provided for as *Soil Tests*.

APPARATUS AND COMPENSATION FOR FARM TESTS.

Dr. Neale had had satisfactory experience with a spring scale weighing 250 pounds, which he suspended at the rear of a wagon from a derrick or crane made by erecting a pole at an angle of 45 degrees from the front end and supporting it by a vertical brace resting on the rear axle. The scale should have a hook instead of a pan, and from this hook a basket may be suspended, or by means of a double rope shocks of small grain or of corn fodder may be easily weighed. It was also voted that where practicable the makers of Farm Tests should be supplied with a rain gauge and thermometer. In respect to compensation it was voted that $10 per acre should be offered for acre tests on the plan adopted for soil tests.

ANALYSIS OF PRODUCE.

This question was discussed chiefly with reference to corn, that crop being more difficult to sample than most others. Professor Atwater described the plan adopted by the Storrs Station; large samples were selected from a sufficient number of shocks in the field, thoroughly mixed, and smaller samples taken. The latter were cut fine, mixed, and sampled again. The last samples were put in bags, weighed, labeled, and stored in the barn until ready to be taken to the laboratory for analysis. They were weighed when taken from the barn and weighed again when analyzed. The bags and contents were weighed separately on account of the changes of moisture of the bags. President Alvord had selected representative plants from each plot, and removed them immediately to the station; Professor Porter had taken average plants green from the field; Dr. Neale favored taking large samples, 400 to 500 pounds, and after drying, shredding them thoroughly, and then taking smaller samples; Professor Whitcher had used the "scientific grinding mill," made at Springfield, Ohio, for this work of shredding samples, with satisfactory results. Dr. Neale had seen a mill in operation in Germany, which had done the work very thoroughly, also a mill for grinding starch for analysis, the latter being practically a mortar and pestle revolving in opposite directions. Dr. Neale stated that, in the analysis of sugar-beets, a German chemist had adopted the plan of selecting every hundredth beet, marking these with a paint brush, and grinding and sampling them.

By arrangement, the gentlemen present waited upon the new Secretary of Agriculture, Hon. J. M. Rusk, who had just come to the Department, and were very courteously received.

GEOLOGICAL HISTORY AND CHEMICAL ANALYSIS OF SOILS.

Much doubt was expressed respecting the advantage to be derived from elaborate soil analysis in this work, but it was deemed desirable that nitrogen determinations at least should be made, and that the geological history of the soil should be determined as closely as possible. In this connection Dr. Neale referred to the great improvements in methods of nitrogen determination lately made by German and other chemists.

PRINTED DIRECTIONS AND FORMS FOR REPORTS OF EXPERIMENTS.

Professor Atwater called attention to the clause in the Hatch act requiring the Department of Agriculture to furnish forms for reports of experiments, and requested suggestions on this point. It was voted that the committee on materials and supplies confer with Professor Atwater in regard to the matter.

Professor Atwater was also requested to prepare explanations of the experiments and directions for carrying them out similar to those used by the Storrs Station.

It was voted to appoint a committee on publication of proceedings of the conference, said committee to be empowered to embody in their report such suggestions respecting further experiments as may be germane to the matter. Messrs. Atwater, Alvord, and Thorne were appointed for this service.

A unanimous vote of thanks was tendered to Professor Atwater for kind attentions shown to the conference, which then adjourned *sine die.*

CHAS. E. THORNE,
Secretary.

EXPLANATIONS AND DIRECTIONS FOR EXPERIMENTS.

SOIL TESTS WITH FERTILIZERS.

The object of these experiments is to enable farmers to study the needs of their soils and the action of fertilizers. Experience in the field, explained by experiments in the laboratory, has clearly demonstrated that:

(1) Soils vary greatly in their capabilities of supplying food to crops. Different ingredients are deficient in different soils. The way to learn what materials are proper in a given case is by observation and experiment. The rational method for determining what ingredients of plant-food a soil fails to furnish in abundance, and how these lacking materials can be most economically supplied, is to put the question to the soil with different fertilizing materials and get the reply in the crops produced.

(2) The chief use of fertilizers is to supply plant-food. It is good farming to make the most of the natural resources of the soil and of the manures produced on the farm, and to depend upon artificial fertilizers only to furnish what more is needed. It is not good economy to pay high prices for materials which the soil may itself yield, but it is good economy to supply the lacking ones in the cheapest way. The rule in the purchase of costly commercial fertilizers should be to select those that supply, in the best forms and at the lowest cost, the plant-food which the crop needs and the soil fails to furnish.

(3) The only ingredients of plant-food which we ordinarily need to consider in fertilizers are potash, lime, sulphuric acid, phosphoric acid, and nitrogen. The available supply of sulphuric acid and lime is often insufficient; hence one reason for the good effect so often observed from the application of lime, and of plaster, which is a compound of lime and sulphuric acid. The remaining substances, *phosporic acid*, *potash*, and *nitrogen*, are the most important ingredients of our common commercial fertilizers, because of both their scarcity in the soil and their high cost. It is in supplying these that phosphates, bone manures, potash salts, guano, nitrate of soda, and most other commercial fertilizers are chiefly useful.

(4) Plants differ widely with respect to their capacities for gathering their food from soil and air; hence the proper fertilizer in a given case depends upon the crop as well as upon the soil.

(5) The results of any given experiment are, in the main, applicable only to the particular case where it is made.

(6) A single season's experimenting does not tell the whole story. To get complete results the trials must be carried through a series of years and crops.

(7) Of course, such experiments may at best fall short of their purpose. Other factors than the plant-food in fertilizers help to decide their value. Soils fail to furnish enough food to crops, not so much because they have not abundant stores as because the materials are not in available forms. The indirect action of fertilizers in improving the mechanical condition of the soil, increasing its absorptive power, and rendering its inert stores of plant-food available, is often of much more consequence than their direct action in supplying plant-food. Hence cheap materials, like lime and plaster, are sometimes more profitable than the costlier chemical fertilizers or even farm manures. Often the lack of fertility of a soil is due not so much to its lack of plant-food as to its physical condition, its texture, and its relations to heat and moisture; or to its lack of absorptive power, the power to hold plant-food, and not allow it to be leached away beyond the reach of the roots of the plants. Such soils want amendments first and fertilizers afterwards. Tillage improves the mechanical condition of the soil, while it also aids in rendering plant-food available. Sometimes tillage is even more important than manure.

(8) The success of experiments with different fertilizing materials as tests of the wants of soils is often impaired by the physical conditions just named, and oftener by two very common sources of error—inequalities of soil and accumulated stores of plant-food in the soil. Land of uniform quality is essential for these experiments. By continued cropping and fertilizing in certain ways soils sometimes become overstocked with some forms of plant-food and deficient in others. These tests are useful in helping to find how to restore the balance in such cases. When the object is to find not what the soil can do with the aid of plant-food left over from past manuring and culture, but what it can furnish from its own resources—in other words, when the natural strength of the soil is to be tested—it is important to select fields worn out by long cropping without manure.

FERTILIZERS USED FOR SOIL TESTS.

Since the ingredients of plant-food of which worn-out soils most commonly fail to supply enough to produce profitable crops are nitrogen, phosphoric acid, and potash, standard commercial materials containing these are used for the experiments. Nitrate of soda, of about 95 per cent purity, containing 16 per cent of nitrogen; dissolved bone-black (superphosphate) with about 16 per cent of phosphoric acid, besides sulphuric acid and lime, and muriate of potash of 80 per cent purity containing some 50 per cent of "actual potash," are employed. These are applied singly, two by two, and all three together, on the different plots. Besides these, plaster (high-grade gypsum) is also used, not only to furnish sulphate of lime to counterbalance that in the superphosphate, but also because of its fertilizing action, which is often very considerable. The materials are put up in bags intended for one-twentieth of an acre. The eight bags thus suffice for eight plots, which, with two unmanured plots, make half an acre. With plots for other fertilizers, unmanured strips between the plots to prevent the plants of one plot from feeding on the fertilizers of the adjoining plots, the experiment will cover considerably more land. The kinds and quantities of materials and of valuable ingredients per plot and per acre are shown herewith:

Experimental fertilizers for soil tests.

Fertilizing materials.			Valuable ingredients.	
Kinds.	Amount per plot.	Amount per acre.	Kinds.	Amount per acre.
	Pounds.	*Pounds.*		*Pounds.*
Nitrate of soda	8	160	Nitrogen	26
Dissolved bone-black	16	320	Phosphoric acid	51
Muriate of potash	8	160	Potash	80
Nitrate of soda	8	160	Nitrogen	26
Dissolved bone-black	16	320	Phosphoric acid	51
Nitrate of soda	8	160	Nitrogen	26
Muriate of potash	8	160	Potash	80
Dissolved bone-black	16	320	Phosphoric acid	51
Muriate of potash	8	160	Potash	80
Nitrate of soda	8	160	Nitrogen	26
Dissolved bone-black	16	320	Phosphoric acid	51
Muriate of potash	8	160	Potash	80
Plaster	8	160		

Besides these it will be well to test the action of farm manures, lime, and other fertilizing materials.

GENERAL DIRECTIONS FOR SOIL TEST EXPERIMENTS.

While the station will do all it can by printed explanations and directions and by the presence and help of its representatives, it especially requests the experimenter to bestow upon the experiments his most thoughtful attention and accurate work. It invites particular attention to the following directions:

"What is worth doing is worth doing well." In furtherance of the purpose of the experiment and its best execution, please note:

The "Condensed directions."—This slip is intended to be taken into the field for use in laying out the experiment.

The blank for report.—This will be furnished by the station. Please look it over while the crop is growing, consider what it asks for, and make up your mind how to collect the facts. If ways of improving the plan occur to you, please suggest them, and, if agreed to on consultation, adopt them, and at any rate accept thanks.

EVERYTHING IN ORDER BEFORE STARTING.

(1) Have your plans complete and clearly in mind, and everything ready before you start. Proper plans at the outset; uniform soil for all the experiments; "worn-out" soils for the soil tests; plots of proper size, shape, and accurately laid out; right application of the fertilizers; good seed; careful measurement of crops; full notes of details; and careful observation of the effects of the fertilizers on succeeding crops, are essential to the best results.

CONVENIENCIES.

(2) It will be well to have at hand, in planting, a small spring balance and a light bucket or coal-hod. With these it is easy to weigh out the fertilizers from the bags, divide the contents of each bag into portions for one or more square rods each, and carry these portions of the fertilizers to corresponding portions of the plot, on which they can be spread. This will greatly help in uniform spreading.

At harvest you will need a scale, and, for such crops as potatoes, a basket holding at least two or three pecks, to determine the quantity of the crop. The produce on each plot can be divided by square rods, and thus weighed and measured in small portions.

A small note-book will be needed to take into the field during the season and put down observations as made. From this you can copy all you wish to preserve in a more substantial book at your leisure.

UNIFORM SOIL.

(3) The soil should be as nearly uniform in quality as possible. There will be more or less variation in different parts of the same field at best. The less there is of this the more reliable will be the experiment. Level land should be chosen if practicable, but if it is sloping, let the plots run up and down the ascent, so that wash by rains will not transfer the materials from one plot to another. Of course the portion chosen for experiment should be a fair sample of the whole field.

KIND OF SOILS FOR TESTS.

(4) The action of the different fertilizers will be most clearly shown on soils that are more or less worn down by culture. To learn what the soil itself can do by its own natural strength, rather than what it will do with the aid of a store of plant food which has been accumulated by natural processes or left over from previous manuring and will obscure the action of the fertilizers, it is important to select worn-out soils. On soils in high condition the results of such tests are apt to be unsatisfactory. At the same time, land which has been generously treated with certain kinds of manures or artificial fertilizers may still be unsuited to certain crops, and tests of soils of this class may give very valuable results.

LAY OUT PLOTS ACCURATELY.

(5) Lay out the whole experimental area and the individual plots as accurately as you can. Measure with chain or tape, if you have it; otherwise with pole marked in feet and inches. Drive good strong stakes firmly into the ground at the boundaries, so that you may be able to tell in this and coming seasons where the divisions are. There should be four stakes for each plot, one at each corner. These will show the boundaries of the plots and of the unmanured space between them. The stake for each plot can be marked with the number of the plot. The marks can be cut in the stakes with a knife. The tag on the bag can be tied to one of the stakes of the plot to which it belongs.

SIZE AND SHAPE OF EXPERIMENTAL FIELD AND OF PLOTS.

(6) If the seed is to be planted in rows the length of the plots can be adapted to the distance of the rows apart. The "Condensed Directions" give figures which will help in calculating the dimensions of the plots and field. If the soil is even, small, short plots will do. But generally it will not be even, and long plots are therefore safer.

An unmanured strip at least 3 feet wide should be left between each two plots, so as to prevent the plants of one from being affected by the manure of another.

ARRANGEMENT OF PLOTS.

(7) The diagram herewith shows a convenient arrangement of plots. It provides for farm manures and lime in addition to the fertilizers of the experimental set. Of course these and other extra materials can be used at discretion. It is very important that several unmanured plots should be left for comparison. Experience justifies the number in this schedule. An even better test of the uniformity of the soil, however, is the duplication of fertilized plots where that is practicable.

Plan of experimental field.

Field.—Length, 213 feet 4 inches; width, 204 feet; area, 43,520 square feet. (One acre is 43,560 square feet.)

Plots.—Length, 204 feet; width, 10 feet 8 inches; area, 2,176 square feet. (One-twentieth of an acre is 2,178 square feet.)

Strips between and outside the experimental plots.—Length, 204 feet; width, 3 feet 4 inches.

The fifteen plots here provided for (ten manured and five unmanured), with the sixteen strips outside and between the plots, make together 40 square feet less than an acre. If one of the outside strips be made 3 feet 6 inches instead of 3 feet 4 inches, the whole will be 43,554 square feet, or 8 square feet less than an acre.

1. Nothing.
2. Nitrate of soda.
3. Dissolved bone-black.
4. Nothing.
5. Muriate of potash.
6. Nitrate of soda and bone-black.
7. Nitrate of soda and muriate of potash.
8. Nothing.
9. Bone-black and muriate of potash.
10. Nitrate of soda, bone-black, and muriate of potash.
11. Land plaster.
12. Nothing.
13. Barn-yard manure.
14. Lime.
15. Nothing.

The width of the plots, 10 feet 8 inches, has been found in practice convenient for use of machinery for planting corn and potatoes, sowing wheat, and harvesting wheat and grass.

APPLICATION OF FERTILIZERS.

(8) The fertilizers should be—

First. Applied evenly over the plots where they belong, and not allowed to get outside.

Second. Well distributed through the soil.

Experiments with concentrated fertilizers are often spoiled, just as crops are injured or lost, through wrong application. Farmers are apt to think the manure must be put close to the seed or the plant will not get the benefit of it. This is wrong. It is not the just-germinated plantlet that needs the manure, but the plant, from the time it is well started until its growth is done. We want not only to give the crop a good start, but to help it out on the home-stretch as well. The roots and their branching rootlets run out in all directions in search of food, and the fertilizers ought to be where as many of the rootlets as possible can get at them. If we distribute the fertilizers as well as we can, the water in the soil, aided by the chemical and physical forces that nature keeps in operation, will do the rest. In illustration of this, remember how well barn manure acts when applied as a top-dressing long before the seed is put in.

But if we concentrate the fertilizers in one place, fewer roots will get them, and these may be injured by coming in contact with them or with their concentrated solutions in the soil. The roots will find their way to the manure and develop more where it lies, it is true; still we should not oblige them to huddle together in one place, but should rather encourage them to spread around, where, with the increased capacity the fertilizer gives them, they can get the more from the soil. Roots join with other natural agents in rendering inert stores of plant food available.

Above all, do not let the fertilizers come too close to the seed. A coarse, dilute material like yard manure may do the plants no harm, but such concentrated fertilizers as potash salts, nitrate of soda, dried blood, or high grade superphosphates may kill them. Since in these experiments it is particularly important that the effect of each fertilizer be fairly tested, it will be well to *mix them with three or four times their bulk of mellow earth before applying*, but this earth should be taken from the plot to which the fertilizer is applied. Moist sawdust, when obtainable, is apt to be more convenient. Do this by all means if applied in the hill or drill. When the plots are accurately staked out and the fertilizers carefully applied and worked in, the plow or harrow may be run across the plots without fear of transporting the fertilizers from one to another, provided the surface is free from stubble, litter, and clods.

SEE THAT ALL IS DONE RIGHTLY.

(9) Attend to the work yourself. Don't trust it to the hired man, unless you are sure he will do it better than you can.

MAKE ACCURATE OBSERVATIONS.

(10) Watch the experiments closely. Note your observations. Make them both as accurate and complete as you can. Put down your notes when you make your observations. Do not trust them to future recollection.

REPORTS.

(11) Make your reports as full and accurate as possible. Keep one copy for your own future use and send the other in, so that your results may be compared and published with others in good season. The benefit will not be yours alone, but you will share with others the good that will come from the combined work of all.

PLANS FOR CONTINUING THE EXPERIMENTS IN COMING YEARS.

To give the experiments their proper value they should be continued through a series of years with the same fertilizers on the same plots, and with either a rotation of crops or with the same crop year after year. It is hoped that a considerable number of the experiments may be thus repeated. For this the stakes bounding the plots must be kept in place.

THIS PROGRAMME IS NOT AS DIFFICULT AS IT SEEMS.

This may seem a pretty heavy programme for ordinary farmers. Of course the circumstances in which you work will require changes which your own good judgment will regulate.

Good things are not to be had without cost, and to those who have the spirit of the investigator—and there are very many who have that spirit—the task is pleasant and not burdensome. Some of the most accurate, thorough, and valuable field experiments ever made in this country have been carried out by farmers.

The following "condensed directions" are for use in the field:

CONDENSED DIRECTIONS.

(1) Have your plans all made and everything ready before you start. Remember that worn-out soil for the soil tests, uniform soil for all, plots long and narrow and accurately measured and staked out, and right application of the fertilizers are essential to the best success. Don't forget the tape or pole for measuring the plots, the scales for weighing, the pail for carrying the fertilizers, and the stakes (four for each plot).

(2) Select a fair average portion of the field to be tested and lay it out as accurately as you can. Leave an unmanured strip at least 3

feet wide between each two plots, to prevent the roots of the plants from feeding on their neighbors' fertilizers.

(3) Designate each plot by a number, as suggested in the diagrams, and corresponding to the number of the fertilizer. Put a strong stake firmly into the ground at each corner of each plot, and mark it with the number of the plot. If the plots are not staked and marked before the fertilizers are applied, you will risk making mistakes. When the fertilizer is applied to a plot, take the tag from the bag and fasten it to one of the stakes for a label.

(4) Distribute each fertilizer evenly over its plot, and do not let it get outside. Lay your plans for doing this in advance, otherwise you may find the fertilizer all used up before you get to the end, or have some left over. Remember what was said about mixing well with the soil, especially when it is put near the seed. If you do not, you may kill some of the seed and injure the growth of the rest.

(5) Be as systematic and accurate as you can, not only in starting the experiments, but in carrying them out, harvesting and measuring the produce and noting the results.

The following figures will be of service in calculating the dimensions of the experimental plots and field. To calculate the size of plot of one-twentieth of an acre, find in the left-hand column, "Width," the figure for the width decided upon; the opposite figure in the right-hand column will represent the length. Or, given the length in the right-hand column, the opposite figure in the left-hand column will be the width. For one-tenth acre plots, of course take double the given length for same width, or double the given width for same length.

One-twentieth-acre plots, width and length.

Assumed width.	Required length.	Assumed width.	Required length.
Rods:	*Feet. Rods. Ft.*	Rods:	*Feet. Rods. Ft.*
One-third	396 = 24 00	Two-thirds	198 = 12 00
Two-fifths	330 = 20 00	Three-fourths	176 = 10 11
One-half	264 = 16 00	Four-fifths	165 = 10 00
Three-fifths	220 = 13 5¼	One	132 = 8 00
Feet:		Feet:	
6	363 = 22 00	11½	189 = 11 8
6½	335 = 20 5	12	182 = 11 00
7	312 = 18 14	12½	174 = 10 9
7½	291 = 17 10	13	168 = 10 3
8	273 = 16 8	13½	161 = 9 13
8½	257 = 15 9	14	155 = 9 7
9	242 = 14 10	14½	150 = 9 2
9½	230 = 15 15	15	145 = 8 13
10	218 = 13 4	15½	141 = 8 8
10½	208 = 12 9	16	136 = 8 4
11	198 = 12 00	16½	132 = 8 00

SUGGESTIONS FOR FURTHER EXPERIMENTS.

The farm experiments for "soil tests," above described, have practically three objects: To enable farmers to study their soils, to serve as object lessons and thus be a means of education, and to bring the stations into connection with the farmers. But field experiments may be made to do more than this.

Co-operative field experiments with fertilizers, rationally planned, carefully carried out, faithfully reported, and interpreted with the aid of the most advanced science, will help greatly towards finding out many of the things it is very important to know. But to make up for the crudities and uncertainties of this kind of experimental work, it is necessary that the same trial be repeated many times, and under a variety of circumstances. If, along with this, we can have proper studies, chemical and physical, of the soils experimented upon, analyses of the plants produced, and, in addition, pot and box experiments whose conditions can be definitely known and controlled, we may hope to gradually obtain the information we need.

At the conference above reported, the writer was requested to embody in this article statements and suggestions previously made by himself, regarding experiments upon the effects of nitrogen, phosphoric acid, and potash in different quantities and different chemical combinations, and upon the relations of different plants to the supply of these fertilizing ingredients of the soil.

As this is written for practical farmers, as well as station experimenters, some explanatory remarks may not be out of place.

EXPERIMENTS FOR STUDYING THE EFFECTS OF NITROGEN IN FERTILIZERS.

Farmers in all the older States of this country and in Europe are spending large amounts of money every year for nitrate of soda, sulphate of ammonia, fish scrap, dried blood, guano, ammoniated superphosphate, and the like. Ostensibly they are buying the fertilizers at from $10 to $100 per ton. Actually they are buying nitrogen at from 10 to 30 cents per pound. But need the farmer spend so much for nitrogen? Or might he use more with profit? These are questions that no one to-day can answer. Indeed, no chemist or botanist can, as yet, so much as tell him how the different plants he cultivates stand related to nitrogen, or for just what ones he must buy it and what ones he may use in rotation with other crops to gather it from nature's stores and furnish it to him without money and without price, save the cost of tillage.

The question of the nitrogen supply is only one of a great many whose solution is most urgently demanded. We must know how to feed our plants or go without food ourselves. We need more light. Some must come from the laboratory and the greenhouse; some must be sought in the field.

THE FEEDING CAPACITIES OF PLANTS.

These experiments bring us face to face with one of the most important problems with which agricultural chemistry has to deal, namely, to what may perhaps be most properly called the feeding capacities of different plants, their power of gathering their supplies of food from soil and air, and the effects of the artificial supply of different ingredients of plant food upon their growth.

A vast deal of experience in the laboratory and in the field bears concurrent testimony to the fact, though we are still deplorably in the dark as to how or why it is so, that different kinds of plants have different capacities for making use of the stores of food that soil and air contain. Of the ingredients of plant food in our soils, the most important, because the most costly, is nitrogen. Leguminous crops, like clover, do somehow or other gather a good supply of nitrogen, where cereals, such as wheat, barley, rye, and oats, would half starve for lack of it, and this in the face of the fact that leguminous plants contain a great deal of nitrogen, and cereals relatively little. Hence, a heavy nitrogenous manuring may pay well for wheat and be in large part lost on clover.

The tendency of late research is to indicate that some, at least, of the plants that make little response to nitrogenous manuring obtain nitrogen from the air. Whatever the facts may be, they are of the greatest importance. Whatever can be done to bring new light upon the problem is worth attempting. One interesting fact brought out by late experimenting is that the corn plant seems possessed of a goodly share of this faculty of obtaining nitrogen from natural sources, though it is by no means safe to say, at present, that it draws much of its nitrogen directly from the atmosphere. But the power it appears to have of getting its own nitrogen, whether from soil alone, or from both soil and air, means more for the future of corn culture than farmers have yet come to realize.

SPECIAL NITROGEN EXPERIMENTS.

The question as to how much nitrogen plants can obtain from the atmosphere is best studied by experiments on a small scale in the greenhouse and laboratory. The question of the profit or loss in using nitrogenous fertilizers is a matter for field experiment. The specific problems to be studied in the experiments here referred to may be stated thus:

First. How do the plants experimented with get on with the "mineral" fertilizers, such as are supplied by superphosphates and potash salts?

Second. More especially, how do they respond to nitrogen when added, in different forms and amounts, to the mineral fertilizers?

Third. And finally, what inferences may we draw as to the feeding capacities of the plants, their power to gather their food from soil and air, and the effects of different materials upon their growth, especial reference being made to the nitrogen supply?

Several reports of the Connecticut Board of Agriculture and publications of the United States Department of Agriculture have contained accounts of field experiments devised for the study of this especial question and carried out by a number of farmers, agricultural colleges, and experiment stations in Connecticut and elsewhere. The idea is to use the "mineral" fertilizers, superphosphate, and potash salt (which are here called "mixed minerals," and supply all of the ingredients of a "complete fertilizer" except nitrogen) as a basis of comparison, and to compare the produce from this mixture with that obtained when nitrogenous materials are added to it; the increased yield in the latter cases being attributed to the nitrogen. The following quotations are from descriptions and directions prepared for the experiments:

> *The object* of this experiment is to test the effects of nitrogenous fertilizers in different amounts and combinations upon the growth of the plant, and inferentially its capacity to gather its nitrogen from natural sources.
>
> *The fertilizers.*—The ingredients and amounts are such as are used in ordinary practice; phosphoric acid and potash being supplied in about the proportions that occur in a corn crop of 50 or 60 bushels, and nitrogen in one-third, two-thirds, and full amount in same crop.
>
> *Forms of nitrogen.*—The nitrogen is supplied as nitric acid in nitrate of soda; as ammonia in sulphate of ammonia, and as organic nitrogen in dried blood.
>
> *Quantities of nitrogen.*—The nitrogen is applied at the rate of 26 pounds per acre in "one-third ration," 51 pounds per acre in "two-thirds ration," and 77 pounds per acre in "full ration."
>
> *Arrangement of plots and fertilizers.*—The ingredients are supplied as—

Partial fertilizers.	Group I. Nos. 1-3.	Each by itself.	Thus testing the effects of ingredients separately, and capacity of soil.
	Group II. Nos. 4-6.	Two by two.	
Complete fertilizers.	Group III. Nos. 7-9.	Nitrogen as nitric acid in nitrate of soda.	Nitrogen in one-third, two-thirds, and full ration.
	Group IV. Nos. 10-12.	Nitrogen as ammonia in sulphate of ammonia.	
	Group V. Nos. 13-15.	Nitrogen as organic nitrogen in dried blood.	

> The schedule provides for twenty plots, of which two are unmanured and eighteen supplied with the experimental fertilizers. Of the latter, three, Nos. 6*a*, 6*b*, and 6*c*, are duplicates of the "mixed minerals" No. 6. This gives four plots of "mixed minerals," one on each side of each of the three groups, III, IV, and V, in which latter the effects of nitrogen are to be tested. This duplicating the "mixed minerals" serves the three-fold purpose of testing the uniformity of the soil, replacing unmanured plots, and showing more accurately the actual effects of the nitrogen.

In the experiments previously carried out on this plan by a number of colleges, experiment stations, and farmers, superphosphate at the rate of 350 pounds, muriate of potash at the rate of 150 pounds, and nitrate of soda at the rate of 150 pounds, 300 pounds, and 450 pounds per acre were employed. In the following schedule these numbers are changed to multiples of 16, to bring them into line with the soil-test experiments, as proposed above.

FERTILIZING MATERIALS FOR SPECIAL NITROGEN EXPERIMENT.

	Kinds.	Amounts per plot.		Amounts per acre.	Nitrogen per acre.
		Two-acre set, for one-tenth acre plots.	One-acre set, for one-twentieth acre plots.		
	PRELIMINARY GROUP.				
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
1.	Nitrate of soda	16	8	160	26
2.	Superphosphate	32	16	320	....
3.	Muriate of potash	16	8	160	....
4.	Nitrate of soda	16	8	160	26
	Superphosphate	32	16	320	....
5.	Nitrate of soda	16	8	160	26
	Muriate of potash	16	8	160	....
6.	Superphosphate, } Mixed minerals	32	16	320	....
	Muriate of potash,	16	8	160	....
	NITRATE OF SODA GROUP.				
7.	Mixed minerals, as No. 6	48	24	480	....
	Nitrate of soda, one-third ration	16	8	160	26
8.	Mixed minerals, as No. 6	48	24	480	....
	Nitrate of soda, two-thirds ration	32	16	320	51
9.	Mixed minerals, as No. 6	48	24	480	....
	Nitrate of soda, full ration	48	24	480	77
6*a*.	Mixed minerals, as No. 6	48	24	480	....
	SULPHATE OF AMMONIA GROUP.				
10.	Mixed minerals, as No. 6	48	24	480	....
	Sulphate of ammonia, one-third ration	12.2	6.1	122	26
11.	Mixed minerals, as No. 6	48	24	480	....
	Sulphate of ammonia, two-thirds ration	24.4	12.2	244	51
12.	Mixed minerals, as No. 6	48	24	480	....
	Sulphate of ammonia, full ration	36.6	18.3	366	77
6*b*.	Mixed minerals, as No. 6	48	24	480	....
	DRIED BLOOD GROUP.				
13.	Mixed minerals, as No. 6	48	24	480	....
	Dried blood, one-third ration	23.3	11.6	233	26
14.	Mixed minerals, as No. 6	48	24	480	....
	Dried blood, two-thirds ration	46.5	23.2	465	51
15.	Mixed minerals, as No. 6	48	24	480	....
	Dried blood, full ration	69.8	34.9	698	77
6*c*.	Mixed minerals, as No. 6	48	24	480	....

PLAN OF EXPERIMENTAL FIELD FOR SPECIAL NITROGEN EXPERIMENT.

With "acre set." Each plot one-twentieth acre.
Whole field one acre.
With "two-acre set." Each plot one-tenth acre.
Whole field two acres.
} Or more with unmanured strips between each two plots.

0	No manure.
1	Nitrate of soda.
2	Superphosphate.
3	Muriate of potash.
4	Nitrate of soda and superphosphate.
5	Nitrate of soda and muriate of potash.
6	Superphosphate and muriate of potash. "Mixed minerals."
7	Mixed minerals plus nitrate of soda. One-third ration.
8	Mixed minerals plus nitrate of soda. Two-thirds ration.
9	Mixed minerals plus nitrate of soda. Full ration.
6*a*	Mixed minerals. Duplicate of No. 6.
10	Mixed minerals plus sulphate of ammonia. One-third ration.
11	Mixed minerals plus sulphate of ammonia. Two-thirds ration.
12	Mixed minerals plus sulphate of ammonia. Full ration.
6*b*	Mixed minerals. Duplicate of No. 6.
13	Mixed minerals plus dried blood. One-third ration.
14	Mixed minerals plus dried blood. Two-thirds ration.
15	Mixed minerals plus dried blood. Full ration.
6*c*	Mixed minerals. Duplicate of No. 6.
00	No manure.

RESULTS OF SIMILAR EXPERIMENTS.

The following statements regarding the results of experiments conducted on plans similar to those above described may not be out of place here.* The "general" and "special" experiments referred to were essentially the same as the "soil tests" and "special nitrogen experiments" above described. Several hundred were made and reported to the writer.

EFFECTS OF NITROGENOUS FERTILIZERS UPON CORN.

Estimating a bushel of corn, with its cobs and stalks, to contain 1⅓ pounds of nitrogen, and to be worth 80 cents, the effect of the nitrogenous fertilizers in the special and in the general experiments may be summarized as follows, remembering that the superphosphate and potash salt ("mixed minerals") supplied the amounts of phosphoric acid and potash in a crop of not far from 55 or 60 bushels, which would also contain about 72 pounds of nitrogen.

---

* From article by the author in Report of the New Jersey Board of Agriculture for 1884 and 1885.

In the general experiments of the mixture of 300 pounds superphosphate and 200 pounds muriate of potash they brought, on the average of fifty-three experiments, about 43½ bushels of shelled corn per acre. The special experiments, however, seem to me a fairer test of what the fertilizers may do, because, while made in all sorts of weather and on worn-out soils, they were nearly all on soils and in latitudes fit for corn, as many of the general experiments were not. In these the mixture of 300 pounds superphosphate and 150 pounds of potash salt, which can be bought for $8.25, brought on the average 43 bushels of shelled corn per acre. Omitting experiments on one farm, that of Mr. W. C. Newton, of Durham, Conn., the results of which are very exceptional, the average is 44½ bushels.

The experiments of the four seasons bear almost unanimous testimony to two things: The corn was helped but little by nitrogen in the fertilizers, and it gathered a good deal from natural sources. The increase of crop and of nitrogen in the crop will appear more clearly if we look at it another way.

	Number of trials.		
	95.	76.	42.
Amount of nitrogen supplied by fertilizers, per acre ....pounds..	24	48	72
Corn crop, which would contain same amount of nitrogen....bushels..	18	36	54
Average increase of corn ....do....	3.6	5.3	6.6
Increase of nitrogen in the crop ....do....	4.8	7.1	8.8

Or, estimating the results in dollars and cents:

	Number of trials.		
	95.	76.	42.
Amount of nitrogen supplied by fertilizers, per acre ....pounds..	24	48	72
Cost	$5.50	$11.00	$16.50
Number of trials in which nitrogen paid for itself.......	21	13	4
Number of trials in which nitrogen failed to pay for itself.............	74	63	38
Average loss in the several trials..	$2.62	$6.76	$11.22

The only cases in which the largest quantities of nitrogen were profitable were in the experiments of Mr. Newton.

The above calculations of pecuniary loss and gain of course apply only to those regions where corn is dear. But even at these rates the nitrogen increased the crop enough to pay its costs in only thirty-eight trials out of two hundred and thirteen. The pecuniary loss rose and fell with the amount of nitrogen used. With mineral fertilizers alone the crop gathered, by the above estimates, some 60 pounds of nitrogen per acre.

The important fact, however, is this: The corn plant has in these trials shown itself capable of getting on and bringing fair yields with small amounts of the less costly mineral fertilizers, even in the worn-out soils of the Eastern States. With this help it has gathered its nitrogen from natural sources, and holds it readily to be fed out on the farm and returned in the form of manure for other crops. In other words, the experiments thus far imply that corn has, somehow or other, the power to gather a great deal of nitrogen from soil or air, or both; that in this respect it comes nearer to the legumes than the cereals; that, in short, corn may be classed with the "renovating" crops. If this is really so, and this can be settled only by continued experimenting, then our great cereal, instead of being simply a consumer of the fertility of our soils, may be used as an agent for their restoration.

FEEDING CAPACITIES OF OTHER CROPS.

The results of the experiments with other crops were briefly summarized as follows in the report above referred to:

> Taking all in all, the potatoes responded well to the superphosphate, the potash salt, and the nitrogenous fertilizers, and the "complete fertilizer" has been most profitable in almost every case where the weather permitted fair growth. None of the other crops, except, perhaps, turnips, have shown such uniformly beneficial results from all the materials.
>
> The experiments indicate very decidedly that the potato plant differs from many others in respect to the effect of these fertilizing materials upon its growth, and imply that it has less capacity than corn for gathering an adequate supply of food from natural sources. It seems to demand a full and immediately available supply of nourishment for its successful growth.
>
> Concerning the other crops, the data at hand are too meager to warrant any general conclusions. * * * In general, however, the experiments accord with the common notion that makes superphosphate almost a specific for turnips. But they imply that even when the superphosphate is supplied in abundance, the turnip is not usually able to gather enough of the other materials for a full yield unless they are close at hand in readily available forms.

* * * * * * *

I have figured out the amounts of shelled corn, potatoes, and oats obtained per acre in the experiments with each fertilizing mixture, and give averages of all the experiments. If we take the average yield with the mixed minerals alone, that is to say, with all the materials which are ordinarily contained in commercial fertilizers, except nitrogen, at 100, the amounts with the different quantities of nitrogen will be as in the table herewith:

Results of experiments on the effects of nitrogenous fertilizers upon corn, potatoes, and oats.

In experiments with—	Corn.	Potatoes.	Oats.
Estimating the yield with "mixed minerals" at	100	100	100
The yield with mixed minerals and nitrogen, 24 pounds, was	111	127	154
The yield with mixed minerals and nitrogen, 48 pounds, was	112	138	166
The yield with mixed minerals and nitrogen, 72 pounds, was	115	127	171

That is to say, for every 100 bushels of corn obtained with the mixed minerals, we get, by adding 24 pounds of nitrogen per acre, 111 bushels; with 48 pounds of nitrogen, 112, and with 72 pounds of nitrogen in addition to the mixed minerals, 115 bushels. The yield of corn is thus increased slightly by the nitrogen, but the gain is extremely small—out of all proportion to the large cost of nitrogen. The potatoes give a much more decided response to the nitrogen, the 24 pounds increasing the yield from 100 to 127, the 48 pounds bringing it up to 138, while with the 72 pounds it is only 127. I should add, however, that the number of experiments with potatoes was much smaller than with corn. A larger number would give different averages.

The oats responded much more vigorously to the nitrogen, the yield rising to 171 with the largest amount. The number of experiments with oats was less, even, than with potatoes, but since in the cases where oats, potatoes, and corn were grown side by side, the results tallied with the general averages here given, I think the experiments may be taken as indicating very decidedly that the corn is least, while the oats are the most, affected by nitrogen in the fertilizers. These experiments, so far as they go, therefore, imply that we should, in general, be sparing with our use of nitrogen for corn, that we may use moderate quantities on potatoes with profit, and that the oats are especially benefited by it.

There is another way in which the results of the experiments may be summarized so as to show the comparative effects of the phosphoric acid, potash, and nitrogen on the growth of plants. Those who have read the writings of Ville are familiar with his ideas of "dominant" ingredients for different plants. Taking plants and soils as they run, Ville's ideas in this respect are hardly sustained by actual experience. Nevertheless, there appear to be very marked differences in the effects of phosphates and potash salts as well as nitrogenous materials on the growth of the plants, though differences of soil account for as much or more than the differences of the feeding capacities of plants in deciding the effects of the fertilizer. I have taken the results of one hundred and seven experiments with corn and potatoes and put them together in such a way as seems to throw some light upon this part of the problem.

I remarked that the superphosphate, muriate of potash, and nitrate of soda were used singly, two by two, and all three together. If now we take the yield with the superphosphate alone and subtract the yields where no fertilizer was used, we have a difference which we may attribute to the superphosphate. Again, if we subtract the yield with the muriate of potash alone from that of muriate of potash and superphosphate together we get a second difference, which may be attributed to the action of the superphosphate. In the same manner we may subtract the yield with nitrate of soda from that with nitrate of soda and superphosphate together, and obtain a third difference, and finally subtracting the yield with the nitrate of soda and the muriate of potash together from that with the complete fertilizer we have a fourth value for the action for the superphosphate. In each experiment we thus far have four different values for the effect of the phosphoric acid. In the calculations to which I refer these four are put together and their averages are taken as a measure of the effect of the superphosphate in that experiment. In like manner we obtain an average of the four values for the potash in the muriate. A similar estimate may be made of the effect of the nitrogen in the nitrate of soda or other nitrogenous fertilizers, as the case may be.

In some cases these different values for each ingredient—the superphosphate, for instance—are very uniform; in others they are extremely variable, and on examining these computations, as they have been made for a large number of experiments, they seem to me to furnish one of the most severe tests of the accuracy and reliability of such experiments that could be devised.

Out of eighty field experiments with corn but twenty-four were so free from the disturbing influences of unevenness in the soil, drought, cold, etc., as to make them seem to me entirely satisfactory. And of twenty-seven experiments with potatoes only twelve seem to be free from these same disturbing influences. Such are the difficulties which beset field experiments. When, however, we have a large number we may take the average of the whole and be reasonably sure that the disturbing effects of unevenness of the soil will counterbalance each other to a greater or less degree, though experiments that are injured by drought or wet, heat or cold, can, I think, hardly be taken as fair tests in the questions under discussion.

In some cases the corn responded very largely to the phosphoric acid, that is to say, to the superphosphate, and paid very little heed to the potash or to the nitrogen. In other cases the corn responded very largely to the potash, and paid little attention to the other ingredients. In a very few instances it refused to respond to either the phosphate or the potash salt, and at the same time was considerably benefited by the nitrogen. In tabulating the results I have regarded the increase of less than 4 bushels per acre as too small to be taken into account, and in such cases have designated the fertilizing material, superphosphate, muriate of potash, or nitrogen, as "inefficient." Where, on the other hand, the crop responded very largely to either fertilizing material and was increased by less than 4 bushels with either of the others I have called the effective material "the regulating ingredient." Where the fertilizer could neither be the "regulating ingredient" nor inefficient I have called it "more or less efficient."

The table herewith gives the results as estimated in this way. The "select experiments" are those which were reasonably free from the disturbing influences above referred to.

Comparative effects of phosphoric acid, potash, and nitrogen in one hundred and seven experiments with corn and potatoes.

	Corn, eighty experiments.	Potatoes, twenty-seven experiments.	Selected experiments.*	
			Corn, twenty-four experiments.	Potatoes, twelve experiments.
Superphosphate (200 pounds) containing besides sulphuric acid and lime, phosphoric acid, P_2O_5 (48 pounds), per acre:				
Regulating ingredient	27	3	6	....
More or less efficient	35	18	13	11
Inefficient	18	6	5	1
Total	80	27	24	12
Muriate of potash† (200 pounds) containing potassium equivalent to potash, K_2O (100 pounds), per acre:				
Regulating ingredient	11	1	3	1
More or less efficient	25	17	13	11
Inefficient	44	9	8	....
Total	80	27	24	12
Nitrate of soda (200 pounds) containing nitrogen, N (32 pounds), per acre:				
Regulating ingredient	4	....	1	....
More or less efficient	28	16	10	9
Inefficient	48	11	13	3
Total	80	27	24	12

---

* The results of which, as shown by the reports, were not materially impaired by unfavorable weather, unevenness of soil, or other circumstances.

† In several experiments (150 pounds) with 75 pounds potash and 24 pounds nitrogen, respectively.

Some of the conclusions to which these experiments lead may be briefly summarized thus:

As regards the influence of mineral ingredients:

(1) The produce of corn was notably augmented by the potash often and by the phosphoric acid in the majority of the cases.

(2) The produce of potatoes was notably increased by each (phosphoric acid and potash) in almost every case where the influence of the fertilizers was not obstructed by drought, cold, and other disturbing influences.

(3) The produce of oats (in a similar number of experiments) was apparently less increased by the potash than that of either corn or potatoes, while the phosphoric acid was usually beneficial.

As regards the influence of nitrogen:

(4) The corn generally gave but little response to any nitrogenous materials, though in some cases it was materially helped by them. The potatoes and oats responded largely to the nitrogen in nearly every case where circumstances of climate and season permitted.

As regards the feeding capacities of the different plants, the results may be stated thus:

(5) The corn seems (1) to respond largely to the mineral ingredients, and (2) but little to the nitrogenous manures, and (3) to possess in a very high degree the capacity for providing itself with nitrogen from natural sources.

(6) Although, botanically, corn is closely related to wheat, oats, and other cereals, it seems in its physiological relations to the ingredients of its food to have more analogy with the legumes.

(7) The potatoes were helped by each one of the fertilizing ingredients (superphosphate, potash salts, and nitrogen compounds) in almost every case where climate and season allowed. But they gave but moderate yields with the mineral fertilizers, while responding largely to the nitrogen.

(8) These experiments indicate decidedly that potatoes differ from corn in that they have less capacity for gathering for themselves from natural sources sufficient quantities of nitrogen and other nutritive materials. They appear to demand a more ample provision by readily assimilable food close at hand. This difference between the potatoes and the corn may perhaps be explained, in part at least, by the differences in the root.

(9) Oats (in a similar number of experiments) were even more sensitive than the potatoes to the lack of immediately available nitrogen in the soil, and made relatively larger response to the nitrogen of fertilizers.

SPECIAL PHOSPHORIC ACID AND POTASH EXPERIMENTS.

Experiments to test the action of phosphoric acid and potash in different quantities and different chemical combinations can be devised on the plan of the special nitrogen experiments above detailed, starting, like them, from the soil-test experiments as a basis. For the phosphoric acid experiments, for instance, we may have as a "basal mixture" materials furnishing nitrogen and potash, and add phosphoric acid, as is done with nitrogen in the special nitrogen experiments. One hundred and sixty pounds each of nitrate of soda and muriate of potash would serve for the basal mixture. Soluble phosphoric acid can be furnished in the form of dissolved bone-black at the rate of 160, 320, and 480 pounds per acre, which may be called one-third, two-thirds, and full rations. Inasmuch as acid phosphate is sometimes objectionable, it might be well to use precipitated phosphate, prepared by taking a high grade acid phosphate containing 32 per cent of soluble phosphoric acid and adding an equal weight of lime or chalk. Insoluble phosphoric acid in the form of bone or phosphatic rock, finely ground, may be used in quantities furnishing the same amounts of phosphoric acid as the rations of soluble and precipitated phosphoric acid.

For special potash experiments we may use 160 pounds of nitrate of soda and 320 pounds of dissolved bone-black for the basal mixture, and to these add muriate of potash at the rate of 80, 160, and 320 pounds per acre for the one-third, two-thirds, and full rations. Other forms of potash can be used in like manner.

In a meeting held at the Department of Agriculture in 1882, the subject of field experiments with fertilizers was discussed at length, and a committee appointed to suggest plans for co-operative experimenting. At the request of the Commissioner of Agriculture, the writer drew up a series of plans which formed part of a pamphlet on "Co-operative Experimenting as a Means of Studying the Effects of Fertilizers and the Feeding Capacities of Plants," published by the Department in the spring of 1882. A number of experiments of the several kinds indicated have since been carried out by agricultural colleges, experiment stations, and private individuals. It is hoped that the results of these and other experiments in the same line may be collated and published in detail at no distant date. Meanwhile a limited number of copies of the pamphlet referred to can be furnished to any station interested, on application to this office.

SOURCES OF ERROR IN FIELD EXPERIMENTS WITH FERTILIZERS.

There are two very common difficulties with field experiments, unevenness of the soil, and presence in the soil of plant-food which obscures the action of the plant-food in the fertilizers. Often duplicate plots differ as much from one another in yield as plots that receive different manures, and sometimes the unmanured plots produce more than the manured.

Few realize, until they have tried it, the difficulty of getting uniform soil for field experiments. A field or a portion of a field may look uniform, and yet, when it is divided into plots, a crop grown, and the yield for each plot measured, the differences in the produce on the different plots may be considerable. Since these differences can not be avoided entirely, they should be made as small as possible.

The plant-food in the soil, which interferes so seriously with many experiments for testing the action of fertilizers, may come from either natural accumulation or former manuring. That supplied by the natural process, by which the inert plant-food of the soil is made available to plants and by which the soil acquires plant-food from the air, belongs properly to the soil. The farmer ought to make the most he can of what his soil can thus supply to his crops. That from vegetable residues, roots, etc., is always present to greater or less extent, cannot well be removed, and does not seriously disturb an ordinary experiment, though on old grass land it accounts for a small part of the food the plants obtain. That from previous manuring of course interferes with the tests of the action of the experimental fertilizers, and its interference is in direct proportion to its amount. It ought, therefore, to be avoided when the natural strength of the soil is to be tested.

To learn the practical effects of the fertilizers, it is desirable to use worn-out land, that is to say, land which has been reduced by cropping. The methods of rotation practiced in many regions are generally such as to leave such worn-out lands in grass. Then old meadows and pastures are generally the best for field experiments. Of course they will have some available plant-food, but it is just these worn-out soils which receive manure, and their deficiencies are the ones farmers oftenest need to know.

To get around the difficulty of unevenness of soil numerous devices are employed. One is to test the uniformity of the plots by treating all alike the first year, and, if they vary materially, to either attempt to average duplicates so as to make the differences counterbalance, or to allow for the differences in computing the final results. One serious objection to either of these plans is the uncertainty as to the cause of the variation and to whether it will be constant in succeeding years.

The ideal method would be to test the experimental areas by uniform treatment for a series of years, until temporary causes of irregularity, such as came from manuring, tillage, cropping, etc., were eliminated, and to use for experiment only such as prove to be intrinsically uniform. Where feasible, this latter plan is certainly to be recommended.

Another plan consists in making the plots long and narrow, so as to equalize the differences. This, though often successful, is not always so.

The most practical way to eliminate the errors caused by unevenness of soil is doubtless by duplicating the unmanured, or better, the manured plots. The plan sometimes followed in German experiments, of having an unmanured plot between each two manured, is excellent, but involves a large number of waste plots, and furthermore, it would seem that the produce of duplicate manured plots would give fairer tests of the evenness or unevenness of soil than unmanured plots. In the Special Nitrogen Experiments here described there is considerable duplication of manured plots. The essential part of the experiments is the testing of the effects of nitrogen in different amounts. The three mixtures which contain nitrogen in "one-third ration," "two-third ration," and "full ration," in addition to "mixed minerals" (superphosphate and "full potash salt"), are applied on contiguous plots. On each side of this group is a plot with "mixed minerals" alone. Three such nitrogen groups are placed side by side, with "mixed minerals" between. The "mixed minerals," which serve both as tests of the evenness of the soil and of what it will do without nitrogen, are thus used four times and each quantity of nitrogen three times in each experiment. This duplication of manured plots, which small plots make feasible, has been found very satisfactory.* Another excellent plan consists in duplicating the whole experiment by making two series of plots alike, except that the order of one is the inverse of the other. This is accomplished by dividing the whole field by a line through the middle crossing the plots. The fertilizers are then applied in order on one side of this dividing line and in the inverse order on the other.

SIZE OF EXPERIMENTAL PLOTS.

Ordinarily, plots of 8 square rods, one-twentieth acre, each, seem as satisfactory as any. In most cases, two plots of one-twentieth would be preferable to one of one-tenth acre. At least, such is the impression left on my mind after looking over the reports of several hundred experiments sent me for examination. Before this experience I was inclined to larger areas, but I have been surprised at the uniformity of results from small plots, when they are long and narrow. Some of the most satisfactory field experiments have been on plots of only 4 square rods.

---

* As explained in the report of the Connecticut Board of Agriculture, 1880, pp. 345–63, a comparison of the yields on the different plots of experiments on these plans offers a peculiar but apparently very rigid test of the evenness of the plots.

SPACES BETWEEN THE EXPERIMENTAL PLOTS.

Another frequent cause of inaccuracy in field experiments with fertilizers is the extension of the roots of the plants of one plot into the soil of the next one, so that the plants feed upon their neighbors' fertilizers. The roots of corn, for instance, extend laterally several feet, and unless something is done to prevent, the plants may get so much material that does not belong to them as to vitiate the results of the experiments. The yield on an unmanured plot between two manured ones is often much larger than on another unmanured plot whose plants have not the fertilizers close at hand to draw upon. The best plan to obviate this is to leave unmanured strips between the experimental plots so wide that the roots will not reach across them. The difficulty can be helped, of course, by plowing between the plots deep enough to cut the roots.

KINDS OF EXPERIMENTAL INQUIRY NEEDED.

The article above referred to urged the importance of co-operative experiments on plans nearly enough alike to make the results capable of being tabulated together for comparison, but added the following:

> What is wanted is not detailed and inelastic schedules, but rather outlines which each experimenter can fill in as seems to him most advisable. Every man knows his own circumstances, and every intelligent worker has valuable ideas of his own, which others have not. It seems to me that the most effective system will be one which will enable each to develop his own ideas, while we all work together and contribute our results to the common fund.
>
> To get the most complete results we need:
>
> (1) Field experiments, to include—
>
> (*a*) The culture of plants on plots of land treated with different manures, and careful weighings and measurements of produce.
>
> (*b*) Where practicable, chemical and physical studies of the soil.
>
> (*c*) In many cases, chemical analyses of the plants.
>
> (2) Pot [and box] experiments, in which the conditions can be definitely known and controlled, and the needed studies of soil and plants be carried out with equal or greater convenience and accuracy.
>
> Indeed, it is safe to say that there ought to be in the various sections of the country chemical and physical surveys of the land in the behalf of agriculture, as there have been topographical and geological surveys in the behalf of other industries and interests. And in fact this is precisely the direction in which we are tending in this experimental work.

The interest now taken by the experiment stations in field experiments with fertilizers, the prospect of systematic work in this direction, and the duty laid upon the stations by Congress of studying the soils of their respective regions, all emphasize the need of careful consideration of this whole subject.

Field experiments with fertilizers are very useful, especially in the older States where the soil has been depleted by culture, but the information they bring is very limited. We must understand the geology and the meteorology of the different regions, the boundaries of the faunal and floral areas, and the chemistry and physics of the soils themselves, before we can know what we need to know about the agricultural capabilities of the wonderfully diverse soils of the country, and the most advantageous ways to cultivate them.